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Exploring spatio-temporal patterns of plankton diversity and community structure as correlates of water quality in a tropical stream

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ABSTRACT

Ecology of plankton in the downstream reaches of Kaduna River, Zungeru, Niger state, Nigeria was investigated between April and August 2015. Plankton and surface water samples were collected monthly from three stations for analysis of plankton diversity and physico-chemical parameters respectively. Station 1 is relatively unperturbed station located at the outskirts of Zungeru town, station 2 with moderate human activity located in Zungeru town while station 3 with minimal level of anthropogenic activities was located in Wushishi town about 7 km from station 2. The result revealed that the minimum and maximum values for pH water temperature, air temperature, conductivity, dissolved oxygen (DO) biochemical oxygen demand (BOD), phosphate, Nitrate, and secchi disc transparency were 5.38–6.79, 25–31 °C, 26–31 °C, 32–72 μs/cm, 3.50–8.20 mg/l, 1.00–5.00 mg/l, 0.06–1.13 mg/l 0.44–1.31 mg/l, 39.140 cm respectively. A total of 26 species of zooplankton and 24 species of phytoplankton were encountered in the study. The highest number of plankton (20 taxa) was recorded at station 2 while station 1 with 18 taxa and station 3 with 13 representative taxa. For zooplankton, the highest number of taxa was recorded at station 1 (20 taxa), followed by station 3 (14 taxa) and 10 taxa in station 2 were identified. Copepoda of the order cyclopidae dominated all the three stations while Bacillariophyta dominated the three stations for phytoplankton diversity. Canonical correspondence analysis (CCA) ordination was used to determine phytoplankton and zooplankton abundance in relation to the physico-chemical parameters. Nitrate, phosphate and dissolved oxygen had over riding influence on the distribution of the plankton in the water body which indicate that the river is still very productive in terms of providing starter food organisms for higher aquatic life. However, care should be taken to protect the river from further deterioration due to various degrees of human activities.

1. Introduction

Rivers are important ecosystems providing a variety of resources to the communities that depend upon them thereby leading to socio-economic development and sustainability of the environment [1]. Rivers harbour a range of aquatic flora and fauna including plankton which are either directly or indirectly beneficial to man. Plankton (phytoplankton and zooplankton) are identified as important components of this ecosystem and serve as basis upon which the aquatic ecosystem is supported. The plankton community is a dynamic system that responds quickly to environmental changes; hence they act as indicators of water quality [2,3].

Plankton are of immense value as food and play an important role in the natural purification of waters. The relative abundance of chlorophyll is indicative of productive water [4]. Plankton have fast growth rates, thus they can provide meaningful and quantifiable indicators of ecological change over short time scales [2,5].

Phytoplankton are primary producers and regarded as the starting point in aquatic food chain. They are of great relevance to the zooplankton that solely depends on it for survival in the water body. They are highly sensitive to changes in nutrient levels, temperature, pollution, levels of light and increase in predation [6–8]. On the other hand, zooplankton assist in regulating algal and microbial productivity through grazing and in the transfer of primary productivity to fish and other consumers and by so doing they help in improving water quality [9,10].

Planktonic primal in fresh water are dominated by rotifers, cladocerans and copepods. The relative abundance of planktonic communities is influenced by the prevailing abiotic and biotic parameters and these determine their abundance, occurrence and seasonal variations [11]. Plankton is of utmost important in fresh water ecosystem as these are the main source of energy and having a very high nutritive value [12]. Plankters respond quickly to environmental changes because of their short life cycle, hence, their species composition are more likely to indicate the quality of the water which they are found [13].

This study, therefore, is a baseline study of the plankton community of lower Kaduna River, aiming to contribute to the pool of knowledge of plankton ecology in large water bodies and as an environmental impact

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assessment (EIA) for the proposed dam at Zugeru that had already commenced at the beginning of this study. The aim of this study is to determine plankton community composition and abundance at different sampling stations and also to ascertain the dynamics of the plankton communities of lower Kaduna River in relation to environmental variables as the study has not been previously carried out.

2. Materials and methods

2.1. Study area

Zungeru is the Capital of Wushishi local government area of Niger state, Nigeria. It lies within the longitude 6° 9′ 21″ E, and Latitude 9° 48′ 46″ N, with an estimated population of 24,447 people according to GeoName geographical database (July 2015). It is approximately 65 km away from Minna the capital of Niger state. Zungeru is surrounded by mountains, giving it a lower elevation than the surrounding topography. In addition to the Kaduna River, the smaller Nnamaye and Tosheta Rivers flow near the town. The area surrounding the Zungeru is a mixed wooded savanna; species of plants growing in the area include *Afzelia africana*, *Isoberlinia* species, and *Burkea africana*. The town and surrounding country is one of the hottest and most humid parts of Nigeria.

The Kaduna River is a tributary of the Niger River which flows for 550 km through Nigeria. It got its name from the crocodiles that lived in the river and surrounding area. From its source along the western margin of the Jos Plateau, the river flows northwest across the Kaduna plains. Just before it reaches the city of Kaduna, it turns to the southwest, cutting several gorges through rugged terrain between Kaduna and Zungeru. Drainage basin is moist savanna. Dense rain forests line at the lower course of the river, where moisture is more abundant. Annual rainfall averages about 1250 mm (50 in), occurring seasonally between May and September. Great seasonal fluctuations characterize the Kaduna's water flow; peak discharges occur between July and September.

The study site lies within the Savannah region in North Central Nigeria. It is characterized by two seasons (rainy and dry season). The rainy season is from April to October, while the dry season is from November to March. For the pursuant of this research, the study area was divided into three stations, namely:

2.1.1. Station 1

This station designated as site A on the map (Fig. 1) is located at the outskirts of Zungeru town. Water velocity at this station is swift flowing (mean value = 0.24 m/s). The vegetation cover is thick with a dense tunnel of trees and consists mainly of emergent macrophytes and few floating plants such as *Nymphaea lotus*. The marginal vegetation is composed mainly of *Cocos nucifera*, *Havea brasiliensis*, and *Raphia vinifera*. This station was located far from human settlement, therefore it can be classified here as unperturbed site.

2.1.2. Station 2

Station 2 (designated as site B on the map) is at the bridge in Zungeru town. The area has much less aquatic vegetation when compared to Station I. Water velocity is fast and relatively higher than Stations 1 (mean value = 0.49 m/s). The vegetation consists mainly of *Commelina* spp., *Nymphaea* spp., *Pistia stratiotes*, and *Panicum repens*. Artisan fishing, washing of clothes, and bathing are the major human

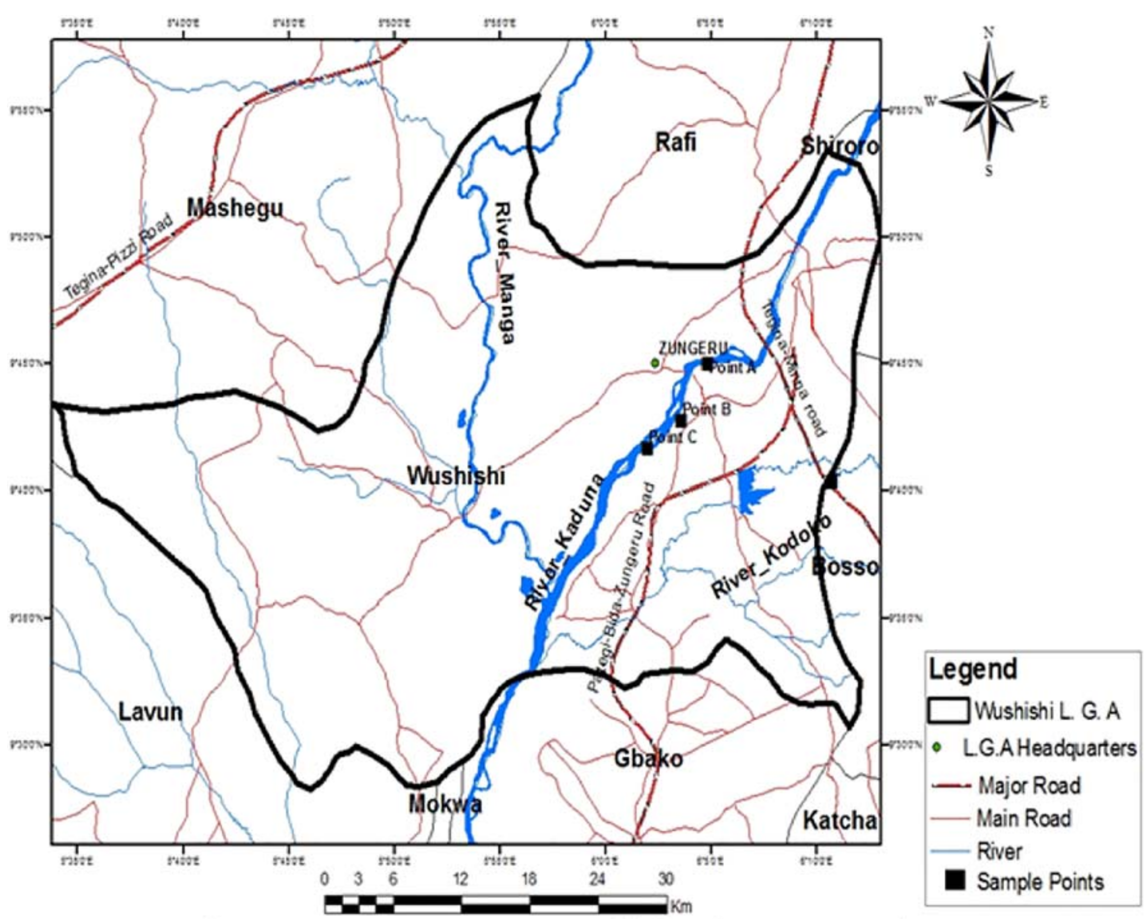

Fig. 1. Sample points distribution along River Kaduna in Wushishi LGA, Niger State, Nigeria. (source: Remote sensing/GIS Lab, Department of Geography, FUT MINNA 2015).

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activities that take place here. This station was categorized as moderately disturbed.

2.1.3. Station 3

Station 3 is located in Wushishi town about 7 km from station 2, under a motorable bridge. The flow velocity of is moderately high (mean = 0.38 m/s) though lower than that in station 2. It has open vegetation, thereby receiving thermal radiation directly from sunlight. The vegetation is sparse consisting mainly of terrestrial plants including *Musa* sp. and shrubs such as *Acrosticuum aureum*. Artisan fishing and grazing by cattle constitute majority of human activities here. This station was categorized as minimally disturbed.

2.2. Sampling techniques

Monthly sampling of the three study site was carried out from April to August 2015 towards the end of every month between 9:00 am to 12:30 pm every sampling day.

2.2.1. Collection and analysis of plankton

Water samples for physico-chemical and plankton analysis were collected monthly for five consecutive months (April to August 2015) at three sampling stations. Samples of zooplankton and phytoplankton were collected using vertical hauls with a zoo- and phytoplankton net of 40 cm diameter, 63 mm and 20 mm mesh size, respectively from the bottom to the surface through the water column at an approximate speed of 0.6 m/s. The samples were collected using a standardized method presented in Edmondson and Winberg [14]. The concentrated samples were collected in small labeled 250 ml bottles. A preservation solution of 70% alcohol and Lugol's iodine were added to zooplankton and phytoplankton sample bottles respectively for fixing purposes. The volume of sampled water that passed through the net was then estimated according to Dalu et al. [2].

The plankton samples were taken to the laboratory at the Hydrobiology unit, Federal University of Technology, Minna, Nigeria for identification and scoring under an inverted microscope OLYMPUS CKX41. The density of zoo- and phytoplankton were determined by counting the numbers present in five 10 ml sub-samples from each site and the mean value was recorded. The quantitative analysis for estimating the abundance of zooplankton was performed with a Sedgwick–Rafter chamber. Plankton were identified using keys provided by Harold [15], Lynne [16], Huynh and Serediak [17], Edward and David [18] and James [19].

2.2.2. Environmental variables analysis

Water samples were collected monthly over a period of 5 months between April and August 2015 at each station. On site, during each sampling event, subsurface water temperatures, dissolved oxygen (DO), temperature-corrected electrical conductivity (EC), total dissolved solids (TDS), pH, depth and flow velocity were measured. A mercury-in-glass thermometer was used for measuring temperature. A HANNA HI 9828 multi-probe metre manufactured by HANNA instruments was used for measuring values of DO, EC, TDS and pH. Water samples were collected in 1-litre plastic acidwashed bottles and transported to the laboratory in a cooler box containing ice. In the laboratory, water samples were analyzed for nitrates and phosphates were measured spectrophotometrically after reduction with appropriate solutions [20] while BOD_5 was computed from the difference between the DO of the first day and DO after five days [20]. Analysis of all samples commenced within 24 h of sampling.

2.3. Data analysis

Range mean and standard error for each parameter and stations were calculated. Physicochemical features of stations were compared using one way ANOVA. Prior to ANOVA, the assumptions of normality and homogeneity of variance were tested using the Shapiro–Wilk and Levene's tests, respectively. When it was found that these assumptions were violated, data were log (x + 1)-transformed, except for pH. Data were actually analyzed by repeated measure ANOVA with sampling month used as a sub factor. Significant ANOVAs ($P < 0.05$) were followed by post hoc {Tukey Honest (HSD)} tests to identify differences between station means. Canonical correspondence analysis (CCA) was used to evaluate relationships between zooplankton communities and environmental variables with PAST statistical package ([21]. Before using CCA, variables that covaried with other variables (Pearson correlation $r >$ 0.80, $P < 0.05$) were removed. Rare species (<2% at a sampling site) were not included in the CCA. Although all physicochemical parameters were included in the early CCA ordinations, those variables with high variance inflation factors (VIF > 20 indicating very strong multicollinearity) were eliminated from the analyses [22]. In addition, variables were log transformed {log (x + 1)} before the CCA analysis to prevent extreme values (outlier) from unduly influencing the ordination. Species-environment correlation coefficients provided a measure of how well variation in community composition could be explained by individual environmental variables. A Monte Carlo permutation test with 199 permutations was used to assess the significance of the canonical axes extracted. Taxa richness (Margalef & Menhinick indices), diversity (Shannon, & Simpson dominance indices), evenness indices and Hutcheson *t*-test for inter-station comparison were calculated using the computer BASIC programme SP DIVERS [23].

3. Results

A summary of some physico-chemical parameters of the study sites of Kaduna River, Zungeru, Niger state from April to August 2015 is given in Table 1. pH, water temperature, conductivity, dissolved Oxygen, biochemical oxygen demand, phosphate, nitrate, secchi disc transparency all showed no significant variation among the three sampling stations ($P > 0.05$) except for Air temperature that showed significant difference among the stations ($P < 0.05$). Generally, Air temperature ranged from 25.00–30.00 °C, Water temperature from 26.00–30.00 °C, pH of 5.38–6.79 was observed across the three stations. Mean dissolved oxygen concentration (3.50–8.20 mg/l) was relatively higher in station 1 than the other two stations while mean biochemical oxygen demand (1.00–5.00 mg/l) was generally low in all the sampling stations. The

Table 1
Physicochemical parameters of the three sampling stations, Kaduna River, Zungeru, Niger state from April to August 2015.

S/N parameters	Station 1	Station 2	Station 3	P value	F. cal
1. pH	6.31 ± 0.15 (5.94–6.79)	6.28 ± 0.09 (6.06–6.61)	6.14 ± 0.19 (5.38–6.44)	0.72	0.33
2. Air temperature (°C)	27.00 ± 0.70 (25.00–29.00)	28.20 ± 0.50 (27.00–30.00)	30.00 ± 0.44 (29.00–30.00)	0.01	6.57
3. Water temperature (°C)	28.20 ± 0.73 (26.00–30.00)	27.80 ± 0.91 (26.00–30.00)	29.00 ± 0.83 (27.00–30.00)	0.59	0.53
4. Conductivity (µs/cm)	56.40 ± 8.20 (32.00–70.00)	59.00 ± 5.71 (41.00–72.00)	63.40 ± 1.80 (59.00–67.00)	0.70	0.35
5. Dissolved oxygen(mg/l)	6.34 ± 0.61 (4.50–8.20)	5.50 ± 0.59 (3.50–7.00)	4.86 ± 0.48 (3.50–6.00)	0.22	1.71
6. Biochemical oxygen demand (mg/l)	3.60 ± 0.50 (2.00–5.00)	2.80 ± 0.48 (1.00–4.00)	2.60 ± 0.50 (1.00–4.00)	0.36	1.10
7. Phosphate (mg/l)	0.29 ± 0.20 (0.06–1.13)	0.45 ± 0.22 (0.06–1.11)	0.45 ± 0.22 (0.06–1.10)	0.84	0.17
8. Nitrate (mg/l)	0.98 ± 0.13 (0.62–1.13)	0.87 ± 0.13 (0.44–1.09)	0.90 ± 0.19 (0.45–1.44)	0.87	0.13
9. Secchi disc - transparency (cm)	76.00 ± 16.10 (40–113)	83.80 ± 21.03 (36–138)	87.60 ± 21.53 (39–140)	0.08	0.91

Note: Values are mean ± S.E. (minimum and maximum values are in parentheses). Some superscript letters in a row do not show significant differences ($P > 0.05$), F. crit value = 3.88.

essential primary productivity nutrient, phosphate (0.06–1.13) and nitrate (0.62–1.44) were low in all the sampling stations. The monthly pattern in rainfall is given in Fig. 2. There was no rain in April, very small rainfall in May and highest in July. The canonical correspondence analysis (CCA) ordination showed a good relationship between phytoplankton species distribution, zooplankton species distribution and environmental variables. The strongest explanatory factor for phytoplankton was the pH and Air temperature that was strongly negative correlated with conductivity, phosphate, water temperature, dissolved oxygen, biochemical oxygen demand and secchi disc transparency (Fig. 3). While for zooplankton, phosphate showed a strongly negative correlation to other parameters (Fig. 4).

3.1. Composition, distribution and abundance of phytoplankton and zooplankton in Kaduna River, Zungeru

The composition and occurrence of phytoplankton and zooplankton recorded in the various stations during the period of the study is shown in Tables 2 and 3 respectively. Quantitatively, the flora of each station was dominated by Bacillariophyta followed by Dinophyta, Cyanobacteria, Chlorophyta and Xanthophyta in that order (Bacillariophyta > Dinophyta > Cyanobacteria > Chlorophyta > Xanthophyta). A combined total of 24 taxa of phytoplankton were encountered in the entire study. Station 1 had more representative taxa (22) in terms of diversity and abundance than station 2 (10) and station 3 (14). The phytoplankton community was dominated by *Calothrix parientino*, *Nitzchia* spp., *Prorocentrum micans*, *Gonatozygon brebesonii*, and *Hydrodictyon reticulatum*. Generally, the *Calothrix parientino* dominated the entire phytoplankton abundance. For zooplankton community, the fauna was dominated by Copepoda (Cyclopida and Calanoida), followed by Cladocerans, Mysida and Anastraca in that order. (Copepoda > Cladocerans > Mysida > Anastraca). A combined total of 46 taxa of zooplankton were encountered and station 1 had more representative taxa (22) followed by station 3 with 14 taxa and station 2 had 10 representative taxa. The zooplankton community comprised only of *Diaphanosoma* spp., *Leptodiaptomus* spp., *Diacyclopsthomasi*, *Eucyclops* spp. and *Mysis* spp. Generally the *Diaphanosoma brachyurum* dominated the entire zooplankton abundance.

3.2. Taxa richness, diversity, evenness and dominance indices

A summary of the taxa richness, diversity, evenness and dominance indices is shown in Tables 4 and 5 for phytoplankton and zooplankton respectively. For phytoplankton, relatively high taxa richness (Margalef index) and diversity index were recorded in station 1 and 3 but was low in station 3. Similarly relatively high evenness was recorded in station 2 and 3. Simpson dominance index value was high in the three stations. Shannon-H index was relatively higher in station 1 and 2 as compared to station 3. Zooplankton on the other hand, recorded relatively higher

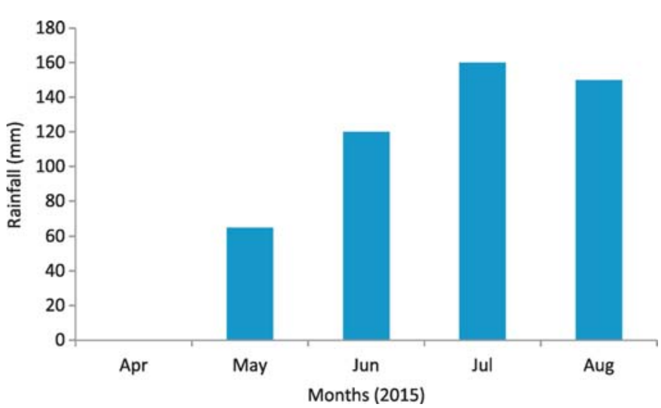

Fig. 2. Typical rainfall distribution pattern in the study area.

taxa richness (Margalef index) and diversity index for station 1 and 3. Simpson dominance index value was also relatively high in stations 1 and 3. Similarly relatively higher evenness was recorded in stations 2 and 3 than in station 1. Shannon H was significantly different among the three stations sampled.

3.3. Temporal distribution of phytoplankton

The abundance and composition of Bacillariophyta was fairly uniform through out the study period (April to August) fluctuating between 43 and 50% of the total phytoplankton composition (Fig. 5a). Dinophyta followed in composition fluctuating between 12 and 23%. The highest percentage were recorded in the months of April and May. Cholorophyta contributed <12% to the total composition of phytoplankton through out the months of study. Their composition was fairly constant but with a sudden drop in August. Xanthophyta was only sporadically present in the study months with relatively high composition in June and July and completely absent in August. Generally, all phytoplankton groups increased gradually with a peak in May (Fig. 5b) and gradual drop recorded from June to August.

For zooplankton groups, Cladocera and Cyclopoida were dominant contributing over 35% each of the total composition in April, while Cladocera dropped in May, Cyclopoida maintained an overiding dominance through out the months of study (Fig. 6a) except in August where Mysida was the dominant group. Amastraca was only sporadically present and contributed <5% to the total composition in all the months of study. Remarkably they were not encountered in the months of June and July. Cyclopoida, Anastraca and Calanoida recorded their peak abundances in May (Fig. 6b) while Mysida recorded its peak in July. Generally, for all the zooplankton groups abundances dropped gradually from April to July and had their lowest abundances in August.

4. Discussion

4.1. Physicochemical characteristics

Physicochemical parameters of the lower Kaduna River varied temporally and did not indicate any significance difference among the study stations. The monthly variations in environmental variables observed is not unconnected with the rainfall regime in this part of the globe, therefore rainfall is considered a dominant factor affecting plankton in tropical waters [6,24,25]. Hydrogen ion concentration (pH) regulates the origin, mobility, and availability of ions and affects different forms in water bodies [26]. In addition, the uptake of nutrients by plants is significantly higher at acidic pH [27]. The minimum and maximum value of pH observed in Kaduna River ranged from 5.3–6.7. This is an indication that the phytoplankton will thrive well with other conditions remaining favourable. Mohammad and Saminu [28] however obtained a much higher value of pH (7.1–9.1) tending towards alkaline in Salanta River, within the same region of study. According to Dalu et al. [2], high pH levels and low levels of nitrate, nitrogen and water transparency in a water body may result in Cyanophyta abundance.

The mean air and water temperature obtained fluctuated between 21 and 34 °C. This is typical of tropical and tropical rivers [6,29]. A range of electrical conductivity of between 32 and 72 µs/cm was registered in the study. The present finding on conductivity is similar to the values recorded by Ibrahim [30] in Challawa River, Kano, Nigeria. The fluctuation of electrical conductivity could be due to variation in the rate of decomposition of organic matter, inflow of nutrients from agricultural runoff and presence of inorganic salt. Dissolved oxygen (DO) is one of the most important parameters that indicate water purity [28]. Its presence is essential in maintaining a variety of forms of biological life in water. The minimum and maximum dissolved Oxygen observed in Kaduna River varied between 3.50 and 8.20 mg/l. This indicates reduced production by phytoplankton and increased organic matter produced by macrophytes. According to DFID [31], dissolved

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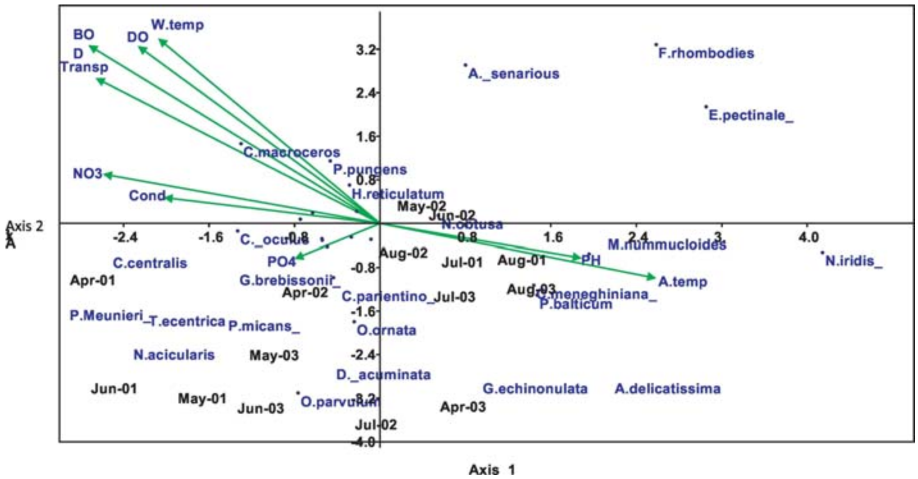

Fig. 3. Canonical correspondence analysis (CCA) ordination showing associations between phytoplankton species and sites sampled at different times and different seasons. BOD-biochemical oxygen demand, DO-dissolved oxygen, Transp-transparency, W.temp-water temperature, No_3-nitrates. PO_4-phosphates, Cond-conductivity, A.Temp-air temperature.

oxygen provides a broad indicator of water quality and that dissolved oxygen concentration in unpolluted water is normally about 8–10 mg/l. This finding is in contrast to the work of Mohammad and Saminu [28] who observed dissolved oxygen range of 5.9 to 16.9 mg/l within the same region probably the water body was less polluted with high flow rate.

Biochemical oxygen demand on the other hand was high. This may be attributed to organic and inorganic oxygen demanding pollutants present in the water sources [28]. Furthermore, phosphate level was low (0.06–1.13 mg/l) as well as low nitrate concentration (<0.90 mg/l) in all the three stations. This result is consistent with the studies carried out by Arimoro and Oganah [32] in Orogodo River, Delta state, Nigeria and Mohammed and Arimoro [25] in a reservoir in Niger state, Nigeria. The state of Nitrogen and Phosphorus depletion and other nutrient requirements of the individual taxa could be important factors in determining the plankton community structure in Kaduna River.

It was observed in this study that physicochemical parameters affected the distribution, occurrence and diversity of plankton. Agouru and Audu [33] findings in River Benue, Nigeria was consistent with our observation. Interactions among nutrient inputs, turbulent mixing, underwater light availability, and grazing pressure can strongly influence the composition of phytoplankton species in the water column, leading to strong and often predictable succession patterns of phytoplankton assemblages in water bodies [34]. As plankton they are essentially non-motile relative to the water mass, but drift with it, and are therefore susceptible to pollutants in the water. For instance, station 3 where irrigation farming often occurs did not indicate sign of toxicity as one would expect that the runoff water may support plankton growth through eutrophication. It could be observed that some plankton species were low in abundance at some of the sampling sites. This may be due to sensitive species disappearing as the water becomes polluted while tolerant ones survived and readily recovered downstream off the point of discharge [35].

4.2. Composition, distribution and abundance of phytoplankton and zooplankton

Most of the identified species of phytoplankton and zooplankton reported in this study are cosmopolitan and have been previously

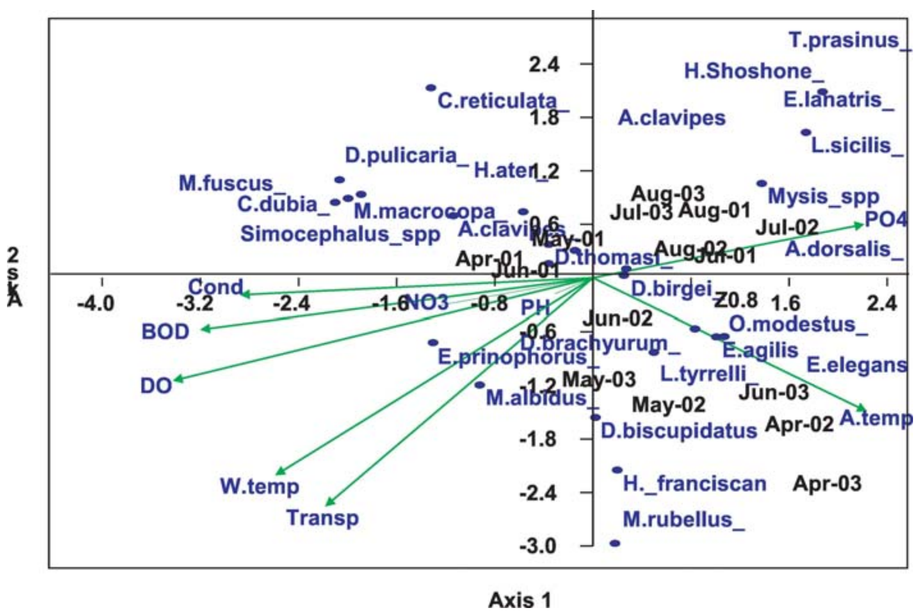

Fig. 4. Canonical correspondence analysis (CCA) ordination showing associations between zooplankton species and sites sampled at different times and different seasons. BOD-biochemical oxygen demand, DO-dissolved oxygen, Transp-transparency, W.temp-water temperature, No_3-nitrates. PO_4-phosphates, Cond-conductivity, A.Temp-air temperature.

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Table 2
Spatial variation, composition and abundance (individual per ml) of phytoplankton in Kaduna River, Zungeru, Niger State, Nigeria.

Division	Genus	Species	ST1	ST2	ST3
Bacillariophyta	*Melosira*	*nummucloides* Agardh, 1824	28	18	0
	Thalassiosira	*ecentrica* Enherenberg, 1904	8	24	20
	Cyclotella	*meneghiniana* Brebisson, 1834	18	14	30
	Coscinodiscus	*centralis* Enherenberg, 1984	32	22	12
	Coscinodiscus	*oculus* Enherenberg, 1840	0	18	22
	Actnoptychus	*senarious* Enherenberg, 1843	0	22	12
	Enotia	*pectinale* Rabenhorst, 1864	0	10	4
	Pseudo-nitzchia	*pungens* Hasle, 1993	24	24	12
	Nitzchia	*acicularis* Smith, 1853	24	20	0
	Nitzchia	*obtusa* Smith 1853	34	12	0
	Neidium	*iridis* Cleve, 1894	0	6	0
	Frustulia	*rhombodies* Toni, 1891	0	14	0
Dinophyta	*Prorocentrum*	*micans* Enherenberg, 1834	24	26	12
	Prorocentrum	*balticum* Loeblich, 1970	16	18	14
	Ceratium	*macroceros* Enherenberg, 1897	10	12	0
	Preperidinium	*meunieri* Pavivard, 1993	24	24	0
	Dinophysis	*acuminata* Claparede and Lachman, 1859	0	14	0
Chlorophyta	*Gonatozygon*	*brebissonii* De Bary, 1858	26	26	12
	Hydrodictyon	*reticulatum* Linnaeus 1824	14	28	16
Cyanobacteria	*Calothrix*	*parientino*Thuret, Flahault and Bornet, 1886	44	30	14
	Gleotrichia	*echinonulata* Richter, 1894	34	36	14
	Aphoncapsa	*delicatissima* West 1942	22	0	0
	Oscillatoria	*ornata* Kutzing and Gomont 1892	24	0	0
Xanthophyta	*Ophiocytium*	*parvulum* Perty1855	2	4	0

observed in other Nigerian inland waters [24,36–38]. The number of species recorded in lower Kaduna River in this work coincides with previous findings from Orogodo River of the South-south region of the country [32] and from River Benue [33].

Majority of the phytoplankton encountered were the Bacillariophyta. The overriding dominance of diatoms has been reported for most water bodies in Nigeria [7,39]. The occurrence of Cyanobacteria, *Gloetrichia echinulata* may be by chance; nevertheless it should not be overlooked as toxic alga have been implicated in the death of aquatic flora and fauna [40]. This finding is in consonance

Table 3
Spatial variation, composition and abundance (individual per ml) of zooplankton in Kaduna River, Zungeru, Niger State. Nigeria.

Genus	Species	ST1	ST2	ST3
Moina	*macrocopa* (Straus, 1820)	8	0	0
Ceriodaphnia	*reticulata* Jurine, 1820	4	0	0
Daphnia	*pulicaria* Forbes, 1893	4	0	0
Ceriodaphnia	*Dubia* Richard, 1894	8	0	0
Simocephalus	Schoedler, 1858	6	0	0
Diaphanosoma	*brachyurum* Lievin, 1857	46	14	26
Diaphanosoma	*birgei* Korinek, 1981	14	0	10
Hesperodiaptomus	*shoshone* Forbes, 1840	2	0	0
Agloadiaptomus	*clavipes* Schacht, 1899	18	10	0
Hesperodiaptomus	*franciscan* Lilljeborg and Richard, 1889	0	16	12
Arctodiaptomus	*dorsalis* Marsh, 1907	0	4	0
Leptodiaptomus	*tyrrelli* Light, 1931	4	8	15
Leptodiaptomus	*sicilis* Forbes, 1882	8	0	0
Eucyclops	*prinophorus* Kiefer, 1931	10	0	6
Diacyclops	*thomasi* Forbes, 1882	32	4	16
Macrocyclops	*fuscus* Jurine, 1820	12	0	0
Macrocyclops	*albidus* Jurine, 1820	10	0	10
Orthocyclops	*modestus* Herrick, 1883	12	0	16
Tropocyclops	*prasinus* Kiefer, 1938	2	0	0
Eucyclops	*elegans*, Herrick 1884	4	20	2
Homocyclops	*ater* Herrick, 1882	0	4	0
Diacyclops	*biscupidatus* Claus, 1857	0	20	0
Eucyclops	*agilis* Koch, 1834	2	0	6
Macrocyclops	*rubellus* Lilljeborg, 1901	0	0	6
Epischura	*lacustris* Forbes, 1882	2	0	6
Eubranchipus spp	Vrrill 1869	0	0	6
Mysis spp	Latreille, 1802	18	30	22

Table 4
Diversity, evenness and dominance indices of phytoplankton at the different sampling stations of Kaduna River.

	Station 1	Station 2	Station 3
No of taxa	18	22	13
No. of individuals	408	422	194
Dominance_D	0.06632	0.05294	0.08938
Simpson_1-D	0.9337	0.9471	0.9106
Shannon_H	2.779	3.001	2.485
Evenness_e^H/S	0.8942	0.9143	0.9235
Taxa richness (Margalef index)	2.828	3.474	2.278

with the work of Okosisi and Osondu [39]. The occurrence of stable genera such as *Oscillatoria*, *Melosira*, *Nitzshia* is consistent with findings in most water bodies in Nigeria [1,41]. Xanthophyta was only represented by one species, *Ophiocytium parvulum* probably because the Xanthophyta are predominantly brackish and marine whereas Kaduna River is a purely freshwater habitat. This finding is in consonance with the work of Ogbuagu and Ayoade [41].

The zooplankton of Kaduna River was dominated with Copepoda followed by the Cladocerans. This result is similar to the finding of Ude et al. [42] in Etchera River, Nigeria. The relatively long period of sampling spanning from April to August 2015 may particularly account for the rich zooplankton recorded. This finding is coincides with the report of Arimoro and Oganah [32] that encountered several zooplankton taxa. The highest number of zooplankton was recorded in station 1 compared with the other two stations. This finding is also consistent to the work of Arimoro and Oganah [32] and may be due to the fairly unpolluted status of the stretch of the water body.

In this study, plankton abundance decreased with increase in the amount of rainfall. This may be due to high turbidity, agricultural runoff, and high flow velocity throughout the rainy season. This finding is in consonance with the reports of Egborge and Onwudinjo [24] in Benin River. It has been reported that rapid currents during wet season damaged and reduced phytoplankton density whereas on the other hand moderate current enhanced the development and abundance of phytoplankton species during dry season [1,39]. High phytoplankton density during the dry season could also be due to better penetration of sunlight, reduced effect of flood regimes, favourable high pH and stimulatory effects of heavy metals which form complexes that allows Phosphate-Phosphorous and Nitrate-Nitrogen to be available for phytoplankton productivity [7].

4.3. Temporal patterns in plankton abundance

The results of the study conducted on plankton species at Kaduna River show there were marked differences in the plankton community composition over the different months. It was also evident that plankton assemblages were closely associated with environmental variables. Changes in environmental factors such as pH, phosphorus, dissolved oxygen, conductivity and water temperature were important in driving or structuring plankton community. Phytoplankton assemblages, which are key primary producers in lakes, reservoirs and various water bodies, are sensitive to variations in multiple environmental factors [7,43].

Table 5
Diversity, evenness and dominance indices of zooplankton at the different sampling stations of Kaduna River.

	Station 1	Station 2	Station 3
No. of taxa	21	10	14
No. of individuals	226	130	159
Dominance_D	0.09359	0.1399	0.09592
Simpson_1-D	0.9064	0.8601	0.9041
Shannon_H	2.668	2.102	2.471
Evenness_e^H/S	0.6862	0.8186	0.8453
Taxa richness (Margalef)	3.690	1.849	2.565

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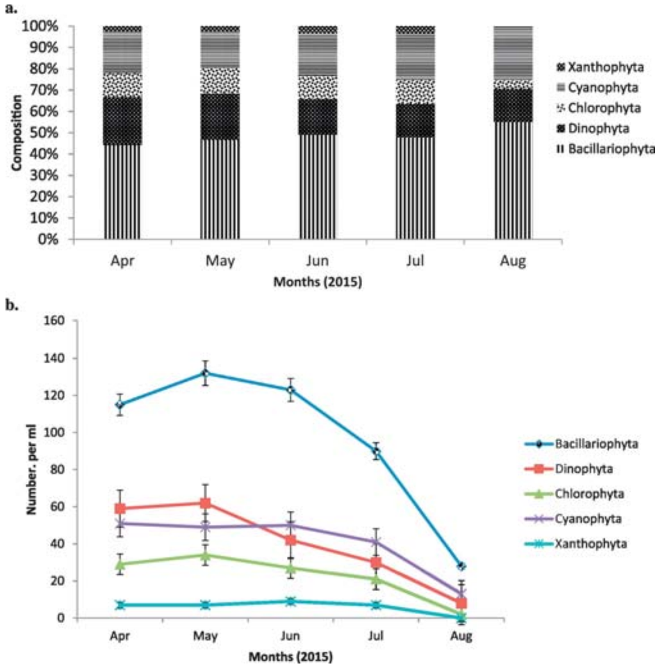

Fig. 5. Temporal changes in (a) percentage composition, (b) total abundance (individual per ml ind) ± standard deviation of phytoplankton in Kaduna River.

High phytoplankton densities observed in May, June and July could be attributed to the increase in nutrient input as a result of the rains which favoured accelerated phytoplankton growth in the early wet season. The high dilution effect of the rains would have accounted for the low total dissolved solutes, and high water transparency between May and July. Similar observation was reported by Dalu et al. [2] in a small tropical reservoir in Zimbabwe.

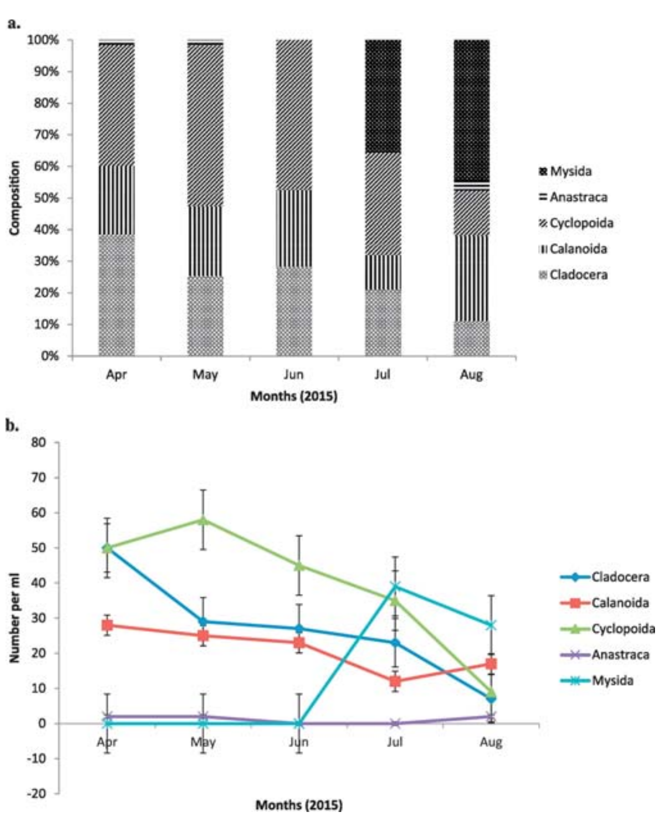

Fig. 6. Temporal changes in (a) percentage composition, (b) total abundance (individual per ml ind) ± standard deviation of zooplankton in Kaduna River.

Generally, station 2 had slightly higher nutrient values (nitrate and phosphate) than the other stations because of the relatively higher impact from various human activities. This perhaps explains the rather high abundance of phytoplanton at that station. However as a result of the unidirectional flow of water, these group of organisms would probale drift to station 3.

5. Conclusion

The data presented here has historical value for future research on the entire stretch of Kaduna River and is also unique in that it represents the first survey of plankton composition, diversity and abundance of lower reaches of the river. Furthermore, not far from these location is where work for the proposed dam in Zugeru for electricity supply has commenced in earnest at the time of this study. This study revealed that the Kaduna River around Zungeru is rich in plankton with a good measure of abundance and diversity. However, the impact of various anthropogenic stressors can be felt and this was depicted by changes in the composition of species assemblages and abundance at various stations. Adequate measure should therefore be taken to minimize the effect of increase human activities around this area. We recommend that further studies should be carried out on plankton assemblages and distributions on the entire stretch of Kaduna River and their role in food web structure of the river involving longer period of sampling should be extrapolated. Furthermore, care should be taken to minimize the entry of effluent and pollutant in the water body so as to maintain low turbidity and suitable light penetration into the water, thereby enhancing the rate of photosynthesis in phytoplankton and overall protection of the zooplankton species observed in this water body.

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